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SELECTION OF
A MAN-MODELLING CAD PROGRAM
TO ASSESS THE PHYSICAL COMPATIBILITY
BETWEEN AIRCREW AND AIRCRAFT

DEFENCE AND CIVIL INSTITUTE
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SELECTION OF A MAN-MODELLING CAD PROGRAM TO ASSESS THE PHYSICAL COMPATIBILITY BETWEEN AIRCREW AND AIRCRAFT

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ABSTRACT

DCIEM has been tasked to review Canadian Forces (CF) aircrew/cockpit compatibility and to make recommendations regarding future aircrew selection standards. Computer man-modelling has been proposed as the method to address the evaluation. In this report, three potential computer-aided design, man-modelling programs (CAR, COMBIMAN and SAMMIE) are evaluated. The ELECTRE multi-criteria decision making process was used to select the most appropriate program. The criteria were based on man-modelling and workspace-modelling features, and the capabilities to address the problems of reach, clearance and vision in aircraft crew stations. The results of the analysis support the recommendation to procure SAMMIE. SAMMIE was also found to be suitable to other work station design applications.

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1. INTRODUCTION

The Directorate of Air Requirements (DAR) has tasked DCIEM to review Canadian Forces (CF) aircrew anthropometry and cockpit geometry, and to identify aircrew selection standards that reflect the physical requirements of current and future cockpits [1]. The aims of the aircrew/cockpit compatibility evaluation (ACCE) are to:

a) determine the critical cockpit dimensions of current CF aircraft;

b) determine corresponding anthropometric dimensions of current CF aircrew;

c) identify current CF aircrew that are physically incompatible with each CF aircraft type;

d) propose a process for determining physical incompatibility between each CF aircraft type and potential aircrew;

e) review CFP 154 standards and recommend required changes;

f) review the anthropometric data for aviators given in MIL-STD-1472 and determine if it adequately reflects CF aircrew anthropometric requirements [2].

For the purpose of this tasking, the term aircrew refers to the pilot and navigator officer classifications. The term cockpit implies all aircraft crew stations occupied by the pilot, co-pilot or navigator.

The major activities of the tasking are as follows:

Phase 1: Examine methods used by the countries participating in Air Standardization Coordinating Committee (ASCC) to determine crew station geometry, aircrew anthropometry and aircrew/cockpit physical compatibility.

Phase 2: Determine a process for evaluating aircrew/cockpit compatibility in the CF.

Phase 3: Determine critical physical tasks performed by aircrew in each CF aircraft crew station.

Phase 4: Determine the geometric characteristics of all CF aircraft crew stations.

Phase 5: Determine the anthropometric characteristics of CF aircrew.

Phase 6: Evaluate CF aircrew/cockpit compatibility using information obtained in Phases 3, 4 and 5 by the process determined in Phase 2.

Phase 7: Recommend required changes to the current CF aircrew selection standards [3].

In Phase 1, methods currently used to evaluate the physical compatibility of aircrew with aircraft cockpits were examined [4]. The methods were drawn from a review of traditional human engineering methods to assess work spaces and known aircraft evaluation techniques employed by countries participating in the Air Standardization Coordinating Committee (ASCC).

Some of the methods employ cockpit fitting trials in real or mock-up aircraft. Such trials require live subjects, anthropometric dummies, partial manikins or stick-figure manikins to represent aircrew. Other methods include the comparison of cockpit geometry specifications with published anthropometric data, drawing board analysis using 2-dimensional manikins, and 3-dimensional computer modelling.

Three-dimensional computer man-modelling was determined to be the most appropriate method to evaluate CF aircrew/cockpit compatibility. The selection was based on the analytical capabilities to assess the operation of controls (reach), vision inside and outside the aircraft, body clearances, and ingress and egress. Therefore, the major recommendation resulting from Phase 1 was that DCIEM acquire an appropriate man-modelling computer-aided design (CAD) program to address the ACCE problem [4]. As one objective of Phase 2 of the tasking, this report presents the results of a comparative analysis of three available man-modelling CAD programs.

2. REVIEW OF MAN-MODELLING CAD PROGRAMS

The desirable features of a CAD program to address the ACCE tasking include man-modelling and cockpit-modelling with interactive graphics capability so that 3-dimensional analyses of reach, body clearance and vision can be performed. The computer systems that have been identified as having effective anthropometric man-modelling programs are: BUBBLEMAN, BUFORD, CAR, COMBIMAN, CYBERMAN and SAMMIE [5]. ERGOMAN, ADAM and EVE have been referred to in the literature [6,7] but provide no details regarding their derivations or applications.

Of the computer programs identified, only SAMMIE is commercially available. CAR and COMBIMAN, which are the property of the US Department of Defense, may be obtained through cooperation within the ASCC. Therefore, CAR, COMBIMAN and SAMMIE are considered to be candidates for use in the ACCE tasking, and are assessed for that application in this report.

In the following sections, general descriptions of the programs CAR, COMBIMAN and SAMMIE are given. Following the descriptions, Table 1 outlines some of the specific features offered by the respective systems.

2.1. CAR

Crewstation Assessment of Reach (CAR) was developed by Boeing Aerospace Corporation for use by the Naval Air Development Centre in the U.S. The purpose of CAR is to estimate the percentage of a given aircrew population that is physically accommodated by a given aircraft crew station [8]. The specification for the program included the requirement that it be simple and inexpensive to run.

CAR was written using Fortran V, a computer language based on ANSI Fortran 77. The most recent version, CAR-IV, became available in 1984 and is not dissimilar to the original program which was developed in 1975.

The aircrew anthropometric data used in the CAR program are either obtained from actual surface anthropometric data of individuals, or are generated from existing population data using a Monte Carlo correlation process [8]. If individual anthropometric data are used, they must deviate less than 3 standard deviations from the means of a control set of data (i.e. USN data, 1964). Therefore, the sample to be evaluated using CAR cannot be radically different from the control population. Accepted input data are transformed into link segments, reference links and reference points, to represent the human skeletal structure (see Figure 1).

The crew station is defined by an anchor point, the design eye point (DEP), seat characteristics, head clearance specifications and hand or foot control positions [8]. The anchor allows the user to position the aircrew to a fixed spot in the crew station (i.e. DEP, non-adjustable seat, adjustable seat with fixed foot position, standing position). The specifications for the seat, head clearance and controls outline the conditions under which the man-model is to perform.

Reach assessments can be completed for up to 50 controls. Each reach is affected by specifying the body part used, type of grip, harness restraint and harness location [8]. Where appropriate, the adjustment range of a control can be represented by two discrete

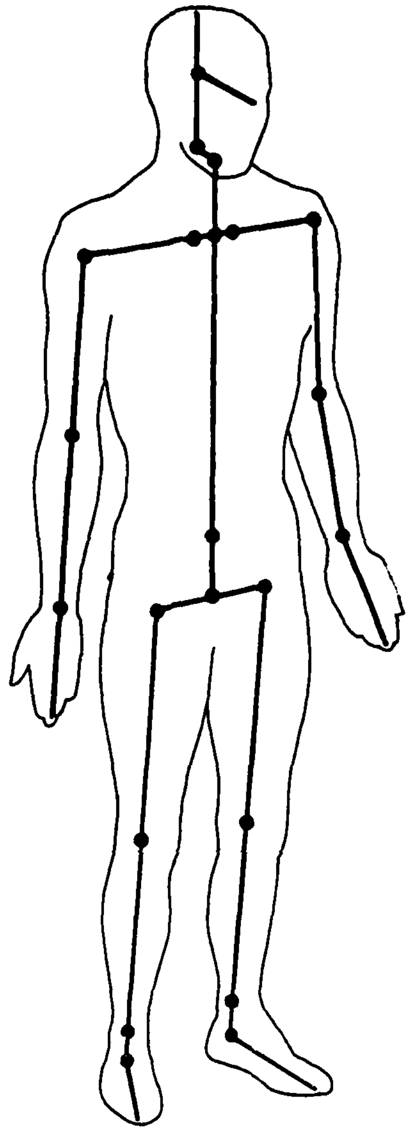

Figure 1. The CAR man-model link system [8].

points.

To use CAR, the investigator defines an aircrew sample and specific parameters of a crew station. The analyses performed include: ability to reach controls, ability to be positioned to the DEP along the line of sight, the ability to be positioned to a specified anchor, and head clearance to the aircraft canopy. The program is intended for interactive use, but will accept data from card-image files. It is not well suited for assessments other than those of reach in aircraft crew stations.

2.2. COMBIMAN

COMputerized BIomechanical MAN-Model (COMBIMAN) was developed for the U.S. Air Force in 1973 to assist in the design and analysis of aircraft crew stations. It can be used as an engineering tool to represent the physical and geometric properties of aircrew and crew stations [9].

The COMBIMAN system has five interactive computer-graphics programs. Four programs are written in Fortran IV and compiled using an IBM Fortran G compiler, and one program is written in IBM assembly language. The most recent update (Version 6) became effective in May, 1981.

The COMBIMAN man-model is composed of link segments, reference links and reference points that are derived from 12 anthropometric surface dimensions [9]. The links can be varied by length, to reflect different proportions and percentiles, and by angular orientation. The man-model is generated internally, in three stages. First, the link system is defined and generated from an anthropometric data source. Next, ellipsoids are generated to represent "enfleshment" that is based on the surface anthropometric data. Last, the ellipsoids are connected with tangential lines to define the man-model's contour (see Figure 2). Standard "erect" and "slumped" seated postures can be employed. When using the system's reach algorithm, automatic joint-movement restrictions are imposed on the model.

The work space model assumes that the components are composed of panels and controls [9]. The crew station can be defined using existing configurations that are prepared off-line and entered to a data file, or be specified interactively at the keyboard. The designer can define up to 250 panels having 1-25 vertices per panel, and up to 150 controls that can be located on or off the panels. Views of the model are selected by specifying the degrees of roll, pitch and yaw, about three orthogonal planes.

To evaluate the compatibility of the man-model in the crew station, the man-model can be varied by proportion and position [9]. A reach algorithm can be employed so that reaches are performed according to programmed movement patterns and limitations. Conversely, the user can position each limb-segment independently, according to his own movement criteria. The 3-dimensional model can be viewed from any plane or from the position of the model's eye. The coordinates of any location in the modelled environment can be readily identified with reference to the standard origin of the (x,y,z) coordinate system, which is the seat reference point (i.e. the point of intersection of the seat-pan and seat-back).

COMBIMAN was developed for crew station applications, however it is possible to model any work space that requires that the operator be seated. The application of the model is limited largely to vision plots and the evaluation of hand reaches to controls.

2.3. SAMMIE

SAMMIE is a System for Aiding Man-Machine Interaction Evaluation. Development of this CAD program was initiated in 1969 at Nottingham University (U.K.) as an ergonomics tool for designers and engineers [10]. Originally, SAMMIE was marketed in the U.K. by Compeda Incorporated. In 1982, the program was bought by Prime Computer Limited and was enhanced for commercial distribution. It became available for industrial application in North America in 1984. The programming language is Fortran 77.

The SAMMIE man-model may be specified according to whole body percentile, specified limb lengths and somatotype [10]. Although the anthropometric data used to generate the man-model are determined by the user, the University of New York is

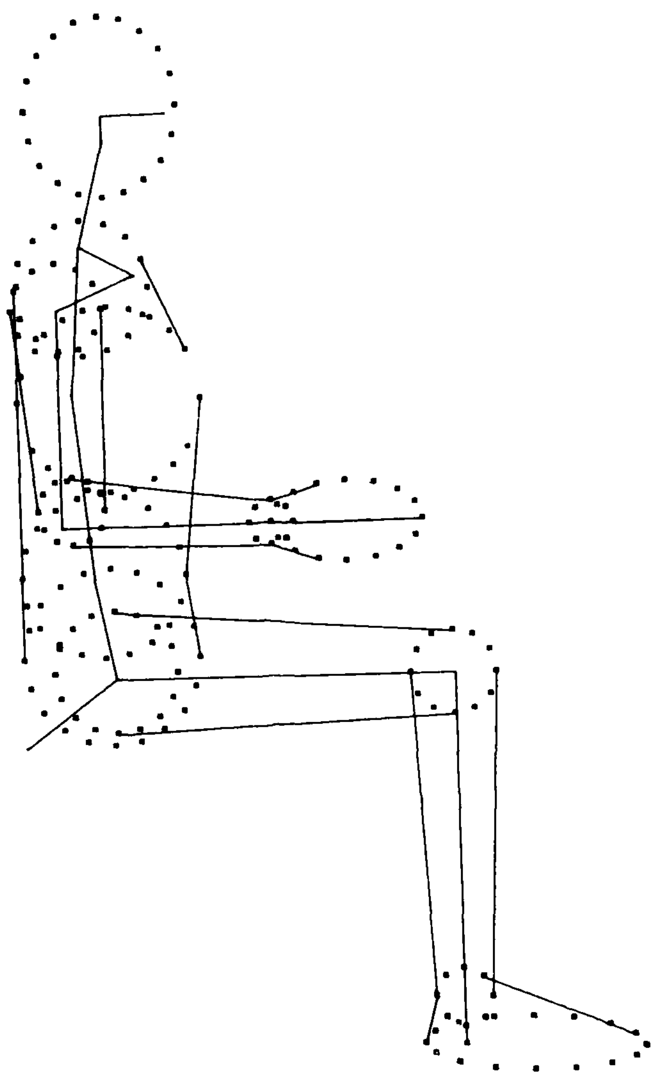

Figure 2. The COMBIMAN man-model link system with enfleshment [9].

currently constructing a library of U.S. military-standard data files for use by SAMMIE users. The military data should be incorporated in the program by June, 1985.

The SAMMIE man-model is composed of link segments and reference points that are derived either from anthropometric surface dimensions or internal body-segment lengths. Enfleshment is achieved using cross-sectional (x,y) data for each of the model's body segments (see Figure 3). Movement of the individual links is under the control of "comfortable" and "maximum" joint constraint data which may be changed to simulate different effects (i.e. normal human postures, restrictive clothing).

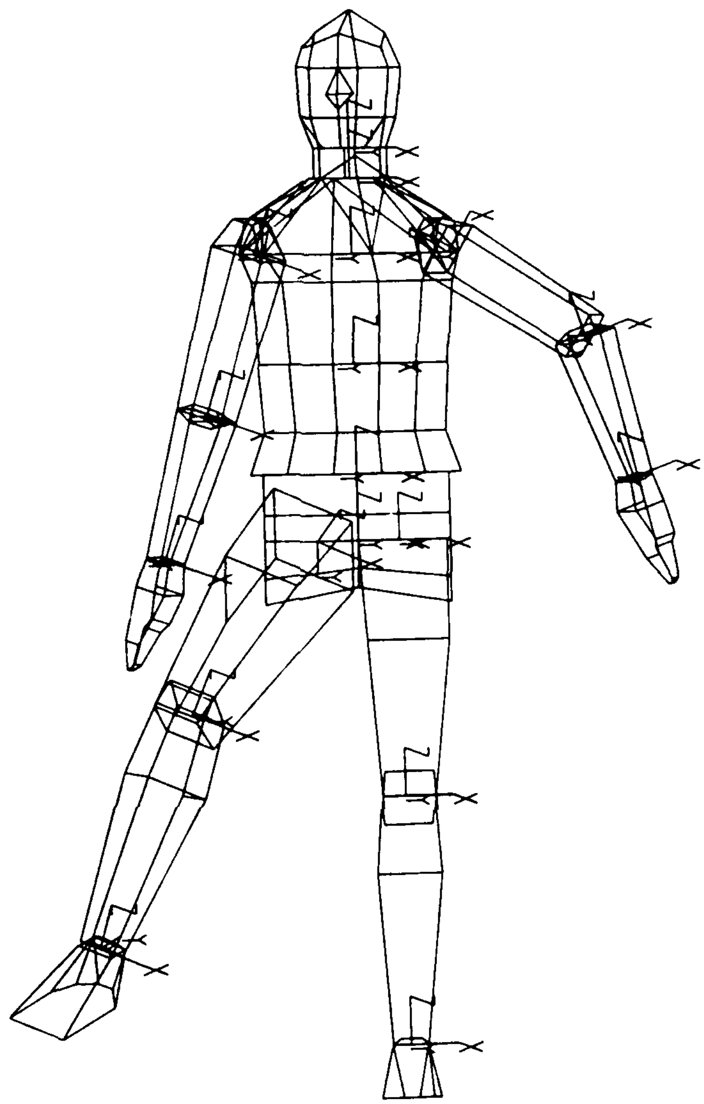

Figure 3. The SAMMIE man-model link system with enfleshment [10].

The workplace-model components are often prepared from engineering drawings or design sketches. They are defined 3-dimensionally, as primitive shapes (e.g. prisms, cuboids and cylinders) or by irregular solids (described by vertices, edges and faces). The spatial and hierarchal relationships of these geometric shapes are specified to establish their orientation in the environment. Workplace models can be generated interactively while using SAMMIE, or entered directly to a data file following off-line preparation [10].

The logical relationships between components of the workplace enable mechanical functions to be simulated (e.g. upward and downward movement of fork lifts on a forklift truck). As with the man-model, movements of workplace components may be logically grouped (e.g. table movement includes all items located on the table surface), or they may occur independently.

Several features distinguish the SAMMIE program from other man-modelling programs. A major feature is its capability to model general equipment-workplace complexes, rather than just aircraft [10]. Many display options are provided including: mirror reflections, four simultaneous views (i.e. plan, side, front and perspective) and a mesh-grid field-of-view reference system. The user can select views from either the man-model's eye position or an external point. Rather than testing operator views or reaches to one point only, the user can define reach and sight paths to a specified series of points. These graphics displays enhance the analysis by taking advantage of man's ability to process large amounts of data when they are presented visually. Two other features of SAMMIE enhance the "realism" of the workplace model. First, structured movement sequences can be specified to simulate the movement of equipment (e.g. raising of a seat through its range of height adjustment). Secondly, multiple numbers of operators can be modelled in the workplace at any one time, serving the needs of the user who must consider the physical interactions of several people in the workplace. Due to these features, SAMMIE is sufficiently general, yet sophisticated enough to be employed in robotics, transportation, materials handling, consumer product, building layout and military design applications [11].

Table 1. A comparison of features offered by CAR, COMBIMAN and SAMMIE.

MAN-MODEL INPUT OPTIONS	CAR	COMBIMAN	SAMMIE
link-length input options			
internal dimensions	–	√	√
external dimensions	√	√	√
percentile values	√	√	√
absolute values (mm)	√	√	√
somatotypes	–	–	√
joint movement options			
movement limit	√	√	√
comfort limit	–	–	√
flex/extend	–	√	√
abduct/adduct	–	√	√
rotate	–	√	√
joint location status	–	√	√
absolute increase	√	√	√
incremental increase	–	–	√
posture			
sit default	√	√	√
stand default	√	–	√
prone default	–	–	√
supine default	–	–	√
crawl default	–	–	√
crouch default	–	–	√
independent posture modification	–	√	√
posture storage	–	√	√
reach options			
right hand	√	√	√
left hand	√	√	√
both hands simultaneously	–	√	√
grasp reach	√	√	√
functional reach	√	√	–
fingertip reach	√	√	√
right foot	√	–	√
left foot	√	–	√
both feet simultaneously	–	–	√
sole reach	–	–	√
toe reach	√	√	√
other simultaneous reaches	–	√	√
reach to item	–	–	√
reach to point (x,y,z)	√	√	√
reach by increments	–	√	√
reach following path of points	–	–	√
reach following contour	–	–	√

(continued)

Table 1. continued.

	CAR	COMBIMAN	SAMMIE
centre of gravity	–	–	√
stickman representation	√	√	√
enfleshment representation	–	√	√
man-model viewing options			
right eye view	–	√	√
left eye view	–	√	√
mid-eye position view	–	√	√
variable cone of vision	–	–	√
head movement only	–	√	√
eye movement only	–	–	√
visual comfort limits	–	–	√
vision up (degrees)	–	–	√
vision down (degrees)	–	–	√
vision right (degrees)	–	–	√
vision left (degrees)	–	–	√
vision to target (x,y,z)	–	√	√
vision to object anchor point	–	–	√
rectilinear vision plot	–	√	√
display additional man-models	–	–	√
WORKPLACE MODEL STRUCTURE			
axis system			
local	–	√	√
global	–	√	√
structure of workplace items			
hierarchal belonging	–	√	√
attachment of objects	–	–	√
reference locus (x,y,z)	√	√	√
methods of modelling			
interactively, at keyboard	√	√	√
remotely, from file	√	√	√
2-D panel	–	√	–
3-D primitive shape	–	√	√
3-D irregular solid	–	–	√
path definitions (x,y,z)	–	–	√
shape duplication	–	–	√
orientation relative to origin	–	√	√
indicate item adjustment range	–	–	√

(continued)

Table 1. continued.

	CAR	COMBIMAN	SAMMIE
COMPUTING AND GRAPHICS FEATURES			
object movement			
drag	–	–	√
shift	–	–	√
rotate	–	–	√
locate	–	√	√
orient	–	–	√
save model	–	√	√
display features			
list item hierarchy	–	√	√
turn item display on/off	–	√	√
indicate object location	–	√	√
mesh grid reference	–	–	√
model views			
perspective view	–	√	√
isometric view	–	√	√
projection (scale factor) view	–	√	√
plan view view	–	√	√
side view view	–	√	√
front view view	–	√	√
simultaneous views	–	–	√
zoom (frame) view	–	√	√
change centre of interest of view	–	√	√
mirror projection	–	–	√
hidden lines removed	–	–	√
hard copy of display	–	√	√
saved file of displayed model	–	√	√
TOTAL	20	54	91

2.4. Optional Programs for use in ACCE

In 1984, DCIEM obtained CAR-II-A from the U.S. Naval Air Development Centre. After the CAR program was installed at DCIEM, an evaluation of the program was undertaken to indicate whether or not CAR would be a viable CAD option to complete the ACCE tasking. CAR was rejected as the primary CAD tool for the ACCE tasking for several reasons [12]. Primarily, it has no graphical capabilities, so visual examination of the analyses is not possible and illustrations for presentation purposes cannot be generated. Furthermore, the analytical capabilities of CAR are limited (e.g. it has no capability to address body clearances).

CAR does show potential as a supplementary tool for the ACCE tasking since it is useful for generating populations of varying anthropometric proportions and for converting individual body segment lengths to percentile equivalents. Other advantages of CAR have been identified by Dooley [5]. Therefore, a contract has been let to determine the validity of CAR's reach, vision and head clearance predictions [13].

During a visit to the USAF Aerospace Medical Research Laboratory, the possibility of DCIEM's acquiring the COMBIMAN program was explored. Since the source code has never before been released by the USAF, there is no guarantee that the program can be obtained [14]. If the program is made available to DCIEM, however, it is understood that there will be no purchase fee.

Discussions with USAF personnel revealed that the program is not compatible with DCIEM's computing facilities. The work required to re-write the software to be compatible with DCIEM's facilities is estimated to require approximately 2 man-years of effort with potential corruption or down-grading of the original program sub-routines [15]. Therefore, considerable cost and time are associated with the acquisition of COMBIMAN for use at DCIEM.

DCIEM personnel first gained experience with SAMMIE in 1982. SAMMIE was examined again in 1984 during a visit to the Ford Motor Company where the program is employed by the Engineering Department for North American Designs. The program became commercially available in North America after being tested for its market potential at Ford Motor Company and Rockwell International. SAMMIE is marketed on the condition that it be supported by Prime computing hardware. The program is available off-the-shelf and can be acquired immediately. The supporting hardware is compact and operates quietly, making it suitable for the office environment.

The plans for future development of the SAMMIE man-model and workplace model have been influenced significantly by Prime Computer clients representing aviation and automotive industries. Their major concerns include the capability to standardize designs and evaluations to U.S. military and Society of Automotive Engineers (SAE) specifications. These demands indirectly serve the needs of the ACCE tasking.

In addition to its potential in the ACCE tasking SAMMIE has the flexibility to address work space problems other than those encountered in aircraft (e.g. ship-bridge design, vehicle evaluation, office lay-out).

On the basis of the considerations discussed above and listed in Table 1, COMBIMAN and SAMMIE were the only programs considered worthy of further consideration for use in the ACCE tasking. Although Table 1 implies that SAMMIE is superior to COMBIMAN, a multi-criteria decision technique was employed as an objective and quantifiable means to select the more appropriate alternative.

3. METHOD

Decision analysis provides a means to choose one of several alternative actions following a systematical analysis. It is accomplished by establishing criteria and choosing the alternative which offers the best solution in meeting the criteria [16].

In a review of multiple criteria decision-making, and its applications to DCIEM's Human Engineering Section, several suitable techniques were identified [16]. A manual was produced to assist personnel in choosing and using the selected multi-criteria techniques.

To determine which of COMBIMAN and SAMMIE is the more appropriate man-modelling CAD program for the ACCE tasking, decision analysis was employed following five steps, as recommended in the manual:

1. problem formulation,
2. quantification of criteria,
3. selection of the decision model,
4. modelling,
5. selection of the preferred alternative [16].

3.1. Problem Formulation

The purpose of acquiring a man-modelling CAD program for the ACCE tasking is to evaluate the physical compatibility of CF aircrew in each CF aircraft crew station. The specific objectives are to assess reach to controls, visual fields (and visual obstructions) and body clearance problems associated with each aircraft.

In order to satisfy the objectives, certain elements are required of the CAD program. The primary elements are: the ability to model man in 3 dimensions, the ability to model aircraft crew stations in 3 dimensions and the ability to perform task sequences for reach, vision and clearance assessments. In addition, the CAD program must exhibit desirable computing features and have inherent analytical integrity.

Each of the main elements that satisfy the objectives was broken down to specific criteria. The criteria were selected on the basis of man-modelling objectives in ergonomics, and the author's personal experience in using man-modelling CAD programs. The criteria are listed in Table 2.

Although program costs and the conditions for their acquisition are very important issues, they were not included in the analysis, since no upper level of cost has been established for the ACCE project or for the development of the associated technology base. Only the characteristics inherent in the respective computing programs were included.

3.2. Quantification of the Criteria

Each of the criteria identified when formulating the problem had to be given a value. Since the values were qualitative in nature, quantification of the criteria was accomplished by giving each criterion a weight. The respective weights that were assigned reflect the author's appraisal of the relative importance of each criterion when choosing among several program options. The weights were normalized to sum to 1. They are listed in Table 2.

3.3. Selection of the Decision Model

Having determined the criteria and their relative weights, the decision model was selected according to the characteristics of the problem [16]. The ELECTRE technique was selected since:

a) the criteria would not be compared against standard values;
b) the criteria would not be considered according to order of preference;
c) all criteria would be considered in comparing the options;
d) importance weights could be assigned to the criteria;
e) the number of options was small;
f) the number of criteria to be used in the comparison was not too great.

3.4. Modelling

When using the ELECTRE technique, the decision is made by determining which option outranks the others. This is accomplished using the following model.

First, each option is appraised individually by rating how well it satisfies each criterion (see "Attribute Values" Table 3). From that point on, the decision options are compared in pairs.

The first two options are ranked by comparing their respective attribute values for each criterion. Each outranking attribute is assigned the importance weight of the corresponding criterion. The model then employs "concordance" indices that are calculated from the results of the rankings of attributes. The option that outranks the other on the basis of the indices is then compared with the third option, using the same model. Elimination of one of the two of options continues until all options have been evaluated and only one remains. That option is considered to be the best option.

The selection of a CAD program to satisfy the ACCE tasking afforded only two alternatives, COMBIMAN and SAMMIE. Therefore, the comparison of only one pair of options was necessary. Subjective attribute values were awarded to the COMBIMAN and SAMMIE programs according to a 5-point subjective rating scale (Table 3). Subsequently, weights were credited to the alternatives for each attribute that outranked the other alternative-attribute.

3.5. Selection of the Preferred Option

According to the ELECTRE decision making technique, the outranking option is determined using two concordance indices [16]. For Index 1, the sum of the weights where Option 1 is better than or equal to Option 2 is divided by the sum of all attribute weights. Since the attribute weights are normalized, Index 1 is affectively the sum of the weights were Option 1 is better than or equal to Option 2. For Index 2, the sum of the weights where Option 1 is better than Option 2 is divided by the sum of weights where Option 2 is better that Option 1.

The threshold values of the indices are established by the decision maker, but are recommended to be 0.7 and 1.0 for indices 1 and 2 respectively [16]. The option that exceeds the thresholds for the two indices is the better of the two options.

Table 2. Decision Criteria and their Importance Weights.

CRITERION (Based on ACCE Objectives)	IMPORTANCE WEIGHT
A MAN-MODEL	
A1 availability of anthropometric data for input	.040
A2 data presentation by %ile and specific data	.035
A3 somatotype representation	.020
A4 a-typical postures possible	.035
A5 flesh contour representation	.040
A6 multiple number of operators modeled at once	.010
B CREW STATION MODEL	
B1 interactive and off-line modelling	.035
B2 hierarchal belonging of elements	.025
B3 movement of elements relative to each other	.030
B4 elimination of individual elements from display	.020
B5 object movement sequence (simulating seat travel)	.010
C COMPUTING FEATURES	
C1 parallel and perspective views	.050
C2 flexible modelling for general applications	.030
C3 graphic illustrations in hardcopy form	.030
C4 simple-to-use	.020
C5 interactive modelling	.025
C6 simultaneous display of different views	.015
C7 transformation of info to publishable form	.030
D REACH ASSESSMENT	
D1 active success/failure distance calculation	.060
D2 joint constraint consideration	.035
D3 variable hand grip on reach	.015
D4 variable body restraint (i.e. effect of harness)	.010
E VISUAL ASSESSMENT	
E1 evaluation of "line of sight" satisfaction	.035
E2 variable peripheral vision of visual field	.020
E3 quantification of extent of visual obstruction	.045
F CLEARANCE ASSESSMENT	
F1 effective indication of solid barrier	.050
F2 calculation of distance required for clearance	.025
F3 multiple number of views of display at once	.035
F4 magnification of portion of view	.015
F5 movement repertoire for objects	.025
G INTEGRITY OF METHOD	
G1 minimum number of assumptions	.025
G2 speed	.020
G3 need for subjective interpretation	.035
G4 subjective confidence in method	.050
TOTAL	1.000

Table 3. Attribute Values and Weights Credited to the Alternatives.

Scale: 1=unacceptable, 2=poor, 3=average, 4=good, 5=excellent

Criterion	Importance Weight	Attribute Values COMBIMAN	SAMMIE	Weights C>S	C=S	S>C
A1	.040	4	2	.040	—	—
A2	.035	4	4	—	.035	—
A3	.020	2	4	—	—	.020
A4	.035	3	5	—	—	.035
A5	.040	3	4	—	—	.040
A6	.010	1	5	—	—	.010
B1	.035	3	4	—	—	.035
B2	.025	1	4	—	—	.025
B3	.030	3	3	—	.030	—
B4	.020	3	3	—	.020	—
B5	.010	2	4	—	—	.010
C1	.050	4	5	—	—	.050
C2	.030	2	5	—	—	.030
C3	.030	3	5	—	—	.030
C4	.020	4	4	—	.020	—
C5	.025	3	3	—	.025	—
C6	.015	2	4	—	—	.015
C7	.030	3	5	—	—	.030
D1	.060	4	4	—	.060	—
D2	.035	4	4	—	.035	—
D3	.015	4	2	.015	—	—
D4	.010	4	2	.010	—	—
E1	.035	3	3	—	.035	—
E2	.020	3	4	—	—	.020
E3	.045	3	5	—	—	.045
F1	.050	2	3	—	—	.050
F2	.025	3	3	—	.025	—
F3	.035	3	4	—	—	.035
F4	.015	?	4	—	.015	—
F5	.025	2	4	—	—	.025
G1	.025	4	3	.025	—	—
G2	.020	3	3	—	.020	—
G3	.035	3	3	—	.035	—
G4	.050	3	4	—	—	.050
TOTALS	1.000			.090	.355	.555

note: C = COMBIMAN, S = SAMMIE

(C>S) + (C=S) + (S>C) = 1.0

4. RESULTS

From the calculations of concordance for the alternatives COMBIMAN (C) and SAMMIE (S), the results were as follows:

A) to determine if COMBIMAN outranks SAMMIE,

$$
\begin{aligned}
\text{Index 1} &= [(C>S) + (C=S)] \,/\, 1 \\
&= 0.090 \ + 0.355 \\
&= 0.445
\end{aligned}
$$

$$
\begin{aligned}
\text{Index 2} &= (C>s) \,/\, (S>C) \\
&= 0.090 \,/\, 0.555 \\
&= 0.162
\end{aligned}
$$

Based upon threshold values of 0.7 and 1.0 for indices 1 and 2 respectively, COMBIMAN does not outrank SAMMIE.

B) to determine if SAMMIE outranks COMBIMAN,

$$
\begin{aligned}
\text{Index 1} &= [(S>C) + (S=C)] \,/\, 1 \\
&= 0.555 \ + 0.355 \\
&= 0.910
\end{aligned}
$$

$$
\begin{aligned}
\text{Index 2} &= (S>C) \,/\, (C>S) \\
&= 0.55 \,/\, 0.90 \\
&= 6.167
\end{aligned}
$$

Based upon the threshold values of 0.7 and 1.0 for indices 1 and 2 respectively, SAMMIE outranks COMBIMAN.

5. DISCUSSION AND CONCLUSIONS

The determination of the best man-modelling CAD program to complete the ACCE tasking was accomplished using the ELECTRE multi-criteria decision technique. The criteria used to evaluate the programs were based on the features considered to be important for man-modelling and workspace-modelling. Of equal importance were the capabilities to address the problems of reach, clearance and vision in aircraft crew stations. The results support the acquisition of the SAMMIE program. Table 1 illustrates many additional features that indicate SAMMIE to be a superior product.

When deciding which of COMBIMAN and SAMMIE is the more appropriate man-modelling program, cost and availability were not included as criteria. There were two principal reasons for that omission. First, it was important to establish which computer program could best satisfy the requirements of the tasking. Secondly, it is very difficult to balance cost and availability since the ACCE tasking is scheduled for completion by mid 1986. However, both computer programs are expensive.

Although there is no purchase fee to acquire COMBIMAN, significant expenses are associated with its acquisition. The cost to translate the source code reflects approximately 2 man-years of effort and use of the appropriate computing facilities [16]. It also reflects a significant delay to the completion of the ACCE tasking.

Sale of SAMMIE is on the condition that hardware support be provided using Prime Computer equipment. For DCIEM's purposes, the hardware requirements include a minicomputer, a colour-graphics computer terminal and a hard-copy unit. Although the hardware and software expenses associated with acquiring SAMMIE sum to approximately $155,000.00, Prime assures their delivery within approximately 2 months of purchase order. A training course is available to SAMMIE users.

Based on the results of the ELECTRE decision-making process and availability, SAMMIE is judged to be the most reasonable means by which to address the ACCE tasking. Furthermore, features such as those listed in Table 1 indicate SAMMIE to be a good investment for future problems associated with the workplace.

6. RECOMMENDATIONS

On the basis of a comparative analysis of the capabilities of three available CAD programs, SAMMIE is recommended for purchase.

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